

## 5. Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

### Overview

#### Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2001

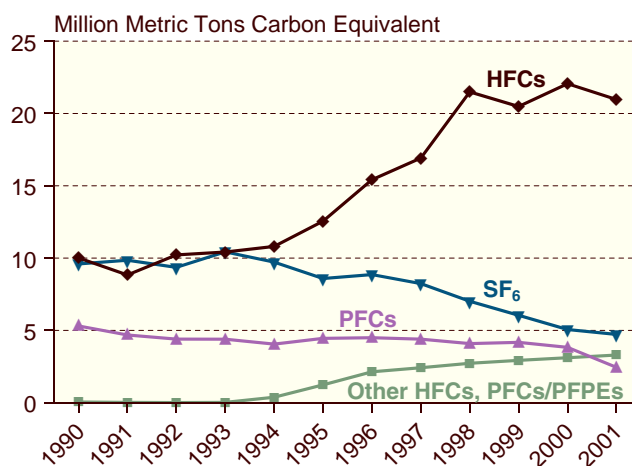
Estimated 2001 Emissions (Million Metric Tons Carbon Equivalent)	31.4
Change Compared to 2000 (Million Metric Tons Carbon Equivalent)	-2.6
Change from 2000 (Percent)	-7.7%
Change Compared to 1990 (Million Metric Tons Carbon Equivalent)	6.5
Change from 1990 (Percent)	25.9%

In addition to the three principal greenhouse gases (carbon dioxide, methane, and nitrous oxide), there are other gases that account for 1.7 percent of U.S. greenhouse gas emissions when weighted by 100-year global warming potential (GWP).<sup>72</sup> The U.S. Environmental Protection Agency (EPA) estimates total emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>) in 2001 at 31.4 million metric tons carbon equivalent—a 7.7-percent decrease over 2000 emissions and a 25.9-percent increase over 1990 emissions. Table 29 summarizes U.S. emissions of HFCs, PFCs, and SF<sub>6</sub> from 1990 to 2001, and Table 30 shows the corresponding emissions in metric tons carbon equivalent.

In summary, revised EPA data for 1990-2000 and new estimates for 2001 show that emissions of HFCs have risen overall except for a decline in 2001; annual emissions of PFCs were nearly unchanged from 1990 through 1999 and declined in 2000 and 2001; and SF<sub>6</sub> emissions have dropped by more than half (Figure 5). In the case of

HFCs, the overall increase in emissions reflects the use of HFCs as replacements for CFCs (chlorofluorocarbons), halons, and other chemicals that are being phased out under the Montreal Protocol because they damage the Earth's stratospheric ozone layer (see box on page 62).<sup>73</sup> CFCs had been widely used as refrigerants, aerosol propellants, and foam blowing agents for many years, but with U.S. CFC production virtually ceasing by 1996, HFCs have been introduced into the market to fill the void in many key applications. The trend in HFC emissions is expected to accelerate in the next decade as HCFCs (hydrochlorofluorocarbons) used as interim substitutes for CFCs are also phased out under the provisions of the Copenhagen Amendments to the Montreal Protocol. Emissions of perfluoropolyethers (PFPEs) have been rising since 1990 because of the recent commercial introduction of new PFPEs for use in various applications in the solvent cleaning industry. PFC

**Figure 5. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2001**



Source: Estimates presented in this chapter.

<sup>72</sup>Preliminary data estimates received by EIA from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, September 2002. Note that EIA calculates emissions in carbon-equivalent units using the GWP values published by the Intergovernmental Panel on Climate Change (IPCC) in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

<sup>73</sup>In previous years, this chapter included emissions estimates and accompanying discussions for a variety of ozone-depleting substances, such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and bromofluorocarbons (halons) and criteria pollutants, such as carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), and nonmethane volatile organic compounds (NMVOCs), which have indirect effects on climate through their effects on atmospheric concentrations of greenhouse gases. Although no longer included in the main body of this report, emissions estimates for ozone-depleting substances and criteria pollutants are included in Appendix D, "Emissions Sources Excluded."

## Alternatives to Chlorofluorocarbons: Lowering Ozone Depletion Potentials vs. Raising Global Warming Potentials

The first international agreement of global cooperation to protect the stratospheric ozone layer was the Montreal Protocol on Substances that Deplete the Ozone Layer, signed in September 1987. In 1990, the Parties to the Protocol agreed to a phaseout of controlled substances—including chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs)—between 1994 and 2040, depending in each case on the substance and the country. The U.S. Environmental Protection Agency (EPA), through its authority under the Clean Air Act, accelerated the phaseout schedule of some of the gases.

The phaseout of ozone-depleting substances fostered the development of alternative fluorocarbons, such as hydrofluorocarbons (HFCs) and HCFCs. Both HCFCs and HFCs are considered environmentally superior because they are largely destroyed in the lowest region of the atmosphere and do not increase the atmospheric loading of chlorine that leads to ozone depletion.<sup>a</sup> Although HCFCs do contain chlorine, they are mostly destroyed before reaching the stratospheric ozone layer. Also, HCFC compounds are only partially halogenated. Their hydrogen-carbon bonds are more vulnerable to oxidation in the troposphere, and therefore they pose only one-tenth to one-hundredth the threat that CFCs pose to the stratospheric ozone layer.<sup>b</sup>

The Ozone Depletion Potential (ODP) index was created to evaluate the relative effects of comparable emissions of these compounds and assist in setting regulatory policy. The ODP of a compound is a fixed value calculated as 1 kilogram of the compound divided by the ODP of 1 kilogram of CFC-11.<sup>c</sup>

Concern over global environmental issues began to push climate change onto the international agenda in the mid-1980s and led to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC created the global warming potential (GWP) index to compare the relative radiative forcing effects of greenhouse gases on the atmosphere. The GWP of a compound approximates the time-integrated warming effect of an emission of a gas relative to that of an emission of an equivalent mass of carbon dioxide (e.g., 100 years). The ODPs and GWPs for various

CFCs, HCFCs, and HFCs are shown in the figures on the opposite page.

While the Montreal Protocol and related regulations cause an industry transition that lowers emissions of high-ODP gases, it increases the emissions of high-GWP gases, particularly in the case of many HCFCs replaced by HFCs. On the other hand, international negotiations by the United Nations Framework Convention on Climate Change (UNFCCC) aim to stabilize atmospheric concentrations of greenhouse gases. Stabilization of concentrations would require lowering of global emissions of greenhouse gases that could be rising as a result of other international agreements. This illustrates the difficulty of balancing conflicting environmental goals.

Although the Montreal Protocol has had success in reversing stratospheric chlorine levels and ozone depletion, it may be increasing the atmospheric concentrations of replacement gases with high GWPs, which would disproportionately raise greenhouse gas emissions—in opposition to the goals of the UNFCCC. The two indexes, ODP and GWP, compare different chemical reactions in the atmosphere and different atmospheric impacts and therefore cannot be combined into a system to prioritize atmospheric pollutants by contrasting disparate qualitative environmental impacts.<sup>d</sup> Neither index can be viewed in isolation, however, as progress in one area can affect the other.

The importance of this issue has been recognized internationally by the UNFCCC, the IPCC, and the Technology and Assessment Panel (TEAP) of the Montreal Protocol. In November 1998, at UNFCCC negotiations, the relationship between efforts to protect the stratospheric ozone layer and mitigate climate change was placed on the agenda. At the November 2002 COP-8 meetings in New Delhi, the Parties reached a decision to address “efforts to protect the stratospheric ozone layer and efforts to safeguard the global climate system, issues relating to hydrofluorocarbons and perfluorocarbons” that requests the IPCC and TEAP “to develop a balanced scientific, technical, and policy-relevant special report . . . by early 2005.”<sup>e</sup>

(continued on page 63)

<sup>a</sup>A.R. Ravishankara, A.A. Turnipseed, N.R. Jensen, S. Barone, M. Mills, C.J. Howard, and S. Solomon, “Do Hydrocarbons Destroy Stratospheric Ozone?” *Science*, Vol. 263 (1994), pp. 71-75.

<sup>b</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

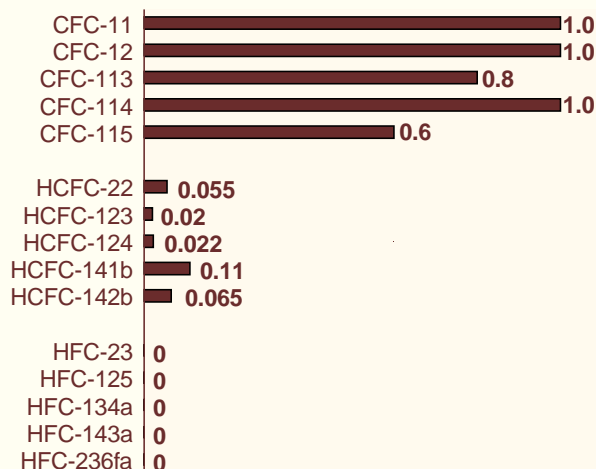
<sup>c</sup>Alternative Fluorocarbons Environmental Acceptability Study, “Atmospheric Chlorine: CFCs and Alternative Fluorocarbons,” web site [www.afeas.org/atmospheric\\_chlorine.html](http://www.afeas.org/atmospheric_chlorine.html).

<sup>d</sup>T.P. Seager and T.L. Theis, “A Thermodynamic Basis for Evaluating Environmental Policy Trade-offs,” *Clean Technology and Environmental Policy*, Vol. 4, No. 3 (2002).

<sup>e</sup>United Nations Framework Convention on Climate Change, 8th Session of the Conference of the Parties, Decision\_CP.8, web site [http://unfccc.int/cop8/latest/15\\_sbsta19add1.pdf](http://unfccc.int/cop8/latest/15_sbsta19add1.pdf).

### Alternatives to Chlorofluorocarbons: Lowering Ozone Depletion Potentials vs. Raising Global Warming Potentials (Continued)

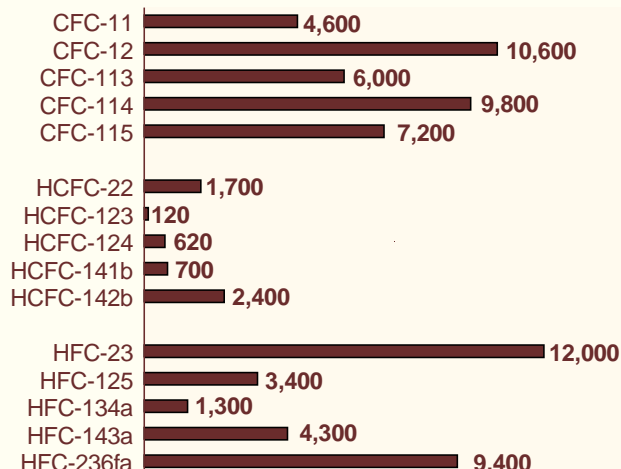
**Ozone Depletion Potentials for CFCs and Alternatives (HCFCs and HFCs)**



Note: The HCFCs and HFCs listed above are the substances studied by the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS). All HFCs have ODPs equal to zero.

Source: Alternative Fluorocarbons Environmental Acceptability Study, "Atmospheric Chlorine: CFCs and Alternative Fluorocarbons" (2002), web site [www.afeas.org/atmospheric\\_chlorine.html](http://www.afeas.org/atmospheric_chlorine.html).

**Global Warming Potentials for CFCs and Alternatives (HCFCs and HFCs)**



Source: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

emissions from the aluminum industry have been falling, and the decrease is only partially offset by increases in PFC emissions from the semiconductor industry. Emissions of SF<sub>6</sub> have declined overall as a result of industry efforts to reduce emissions, mostly from utilities and magnesium processors, and because of the rising cost of the gas.<sup>74</sup>

The Intergovernmental Panel on Climate Change (IPCC) defines three classes of "other gases" to be included in estimating emissions: HFCs, PFCs, and SF<sub>6</sub>. This chapter describes emissions sources and gives emissions estimates for these engineered chemicals, which occur on a very limited basis in nature.<sup>75</sup> Although they are much more potent when measured by their high GWPs than are the principal greenhouse gases, they are emitted in such small quantities that their overall impact is currently small.

The small quantities of HFCs, PFCs, and SF<sub>6</sub> that are emitted have disproportionate effects on overall emissions because of their large GWPs. PFCs and SF<sub>6</sub> have particularly high GWPs because of their scarcity, stability, strong absorption in the atmosphere, and long atmospheric lifetimes.<sup>76</sup> SF<sub>6</sub> is the most potent of the greenhouse gases, with a GWP of 22,200. PFCs, with atmospheric lifetimes in the thousands of years, have GWPs in the range of 7,000 to 9,000. HFC-23 is the most potent of the HFCs, with a GWP of 12,000, while other HFCs have GWPs in the range of 100 to 10,000.<sup>77</sup>

The emissions estimates in Table 29 are taken from data supplied by the EPA's Office of Air and Radiation.<sup>78</sup> The estimates in Table 30 are based on data provided by the EPA's Office of Air and Radiation in units of native gas (thousand metric tons), which were converted to carbon-equivalent units by EIA, using GWP values from

<sup>74</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

<sup>75</sup>See Chapter 1, Table 1. Naturally occurring (pre-industrial) emissions of perfluoromethane (CF<sub>4</sub>) were 40 parts per trillion. Their concentration had doubled by 1998.

<sup>76</sup>See discussion of relative forcing effects of gases in Chapter 1.

<sup>77</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

<sup>78</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

the IPCC's 2001 Third Assessment Report. The 2001 preliminary estimates were developed by the EPA and provided to EIA. They include some revisions to the historical emissions estimates, based on recent runs of the EPA's Vintaging Model and new data for SF<sub>6</sub> (see boxes on pages 65 and 66). The revisions are reflected in the emissions estimates presented in this chapter.

## Hydrofluorocarbons (HFCs)

### U.S. Emissions of Hydrofluorocarbons, 1990-2000

Estimated 2001 Emissions (Million Metric Tons Carbon Equivalent)	21.0
Change Compared to 2000 (Million Metric Tons Carbon Equivalent)	-1.1
Change from 2000 (Percent)	-5.0%
Change Compared to 1990 (Million Metric Tons Carbon Equivalent)	11.0
Change from 1990 (Percent)	109.4%

Since 1990, HFC emissions have accounted for a growing share (66.7 percent in 2001) of total carbon-equivalent emissions of HFCs, PFCs, and SF<sub>6</sub> combined. The EPA estimates U.S. emissions of all HFCs in 2001 at 21.0 million metric tons carbon equivalent, a 5.0-percent decrease from 2000 emissions and a 109.4-percent increase from 1990.<sup>79</sup> The decrease in 2001 is attributable solely to a drop in HFC-23 emissions from HCFC-22 production. Emissions of all other HFCs, most notably HFC-134a, have risen steadily since 1990.

HFCs are compounds containing carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. HFCs are used in many applications as solvents, domestic and commercial refrigerants, firefighting agents, propellants for pharmaceutical and industrial aerosols, foam blowing agents, and in blends for air conditioning refrigerants.

The market for HFCs is expanding as CFCs and other ozone-depleting substances are being phased out under the Montreal Protocol and the Clean Air Act. For example, HFCs are used in fire protection applications to replace Halon 1301 and Halon 1211, which are no longer being produced in the United States.<sup>80</sup> HCFCs, now interim replacements for CFCs, will also be phased out. For example, HCFC-141b and HCFC-142b, which are used as blowing agents in insulation foams, will be replaced by HFCs for some uses.<sup>81</sup>

### Trifluoromethane (HFC-23)

The EPA estimates 2001 emissions of HFC-23 at 1,760 metric tons of gas.<sup>82</sup> Annual emissions have fluctuated since 1990, before dropping by 32.6 percent in 2001. Although emissions of HFC-23 are relatively small, its high GWP (12,000)<sup>83</sup> gives it a substantial potential climatic effect. HFC-23 is created as a byproduct in the production of chlorodifluoromethane (HCFC-22) and is generally vented to the atmosphere. In some cases it is captured for use in a limited number of applications. While production of HCFC-22 continues to grow (by 35 percent from 1990 to 2000), emissions of HFC-23 from this source have declined (by 15 percent from 1990 to 2000), and the intensity of HFC-23 emissions (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) has declined by 37 percent from 1990 to 2000.<sup>84</sup>

HCFC-22 continues to dominate the refrigerant market for stationary refrigeration and air conditioning (including chillers, room and household (central) air conditioners, and dehumidifiers).<sup>85</sup> HCFC-22 is also used as a blowing agent component for polyurethane foams and extruded polystyrene foams. The EPA administers a voluntary program with HCFC-22 producers to reduce HFC-23 emissions, which has helped to offset the rising demand for HCFC-22 in the short term. In the long term, domestic production of HCFC-22 for non-feedstock uses will be phased out by 2020 under the U.S. Clean Air Act, pursuant to U.S. agreements under the Copenhagen Amendments to the Montreal Protocol, although its production for use as a feedstock in the production of other

<sup>79</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002. Note that EIA calculates emissions in carbon-equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

<sup>80</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?applications/others/firefighting/main\\_appli/main.htm](http://www.fluorocarbons.org/frame.htm?applications/others/firefighting/main_appli/main.htm).

<sup>81</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?applications/insulation/main\\_appli/main.htm](http://www.fluorocarbons.org/frame.htm?applications/insulation/main_appli/main.htm).

<sup>82</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

<sup>83</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

<sup>84</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

<sup>85</sup>C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).



### The EPA Vintaging Model: Estimation Methods and Uncertainty

The U.S. Environmental Protection Agency (EPA) uses a detailed Vintaging Model for equipment and products containing ozone-depleting substances (ODS) and ODS substitutes to estimate actual versus potential emissions of various ODS substitutes, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The model estimates the quantities of equipment and products sold each year that contain ODS and ODS substitutes, and the amounts of chemicals required for their manufacture and/or maintenance over time. Emissions from more than 40 different end uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time.

<sup>a</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), Annex J, web site [www.epa.gov](http://www.epa.gov).

For most products (refrigerators, air conditioners, fire extinguishers, etc.), emissions calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture; and disposal emissions, which occur when the equipment is discarded. By aggregating the data over different end uses, the model produces estimates of annual use and emissions of each compound.<sup>a</sup> The EPA is consistently making improvements to the model to use more accurate data from the industries and to reduce uncertainty.

chemicals (fluorinated polymers) will be allowed to continue indefinitely.<sup>86</sup>

### Tetrafluoroethane (HFC-134a)

According to EPA estimates, emissions of HFC-134a, which has a GWP of 1,300,<sup>87</sup> have grown from 564 metric tons in 1990 to 31,552 metric tons in 2001.<sup>88</sup> The 2001 estimate is 9.2 percent higher than that for 2000. Since 1994, HFC-134a has been the automobile industry standard for replacing CFCs in air conditioners for passenger cars, trucks, trains, and buses, because it is nonflammable and has low toxicity. It is also used for domestic refrigeration and freezing, as a propellant for industrial and pharmaceutical aerosols, as a solvent, and as a blowing agent for extruded polystyrene foams.

Automobile air conditioners are subject to leakage, with sufficient refrigerant leaking (15 to 30 percent of the charge) over a 5-year period to require servicing. On its Form EIA-1605, General Motors (GM) reported total HFC-134a emissions of about 2,566 metric tons of gas in 1999.<sup>89</sup> GM based its estimate on an assumed annual leakage rate from mobile sources of 10 percent per year. With GM vehicles accounting for about one-third of the

U.S. light-duty fleet,<sup>90</sup> the GM emissions estimate implies that total U.S. HFC-134a emissions from mobile air conditioners were equal to about 7,700 metric tons in 1999. Emissions from this source are expected to continue to increase in the near future, as the replacement of vehicles using CFCs proceeds at a rapid pace.

In addition to its use in all new automobiles, an automotive aftermarket for HFC-134a has also developed. Spurred by rising prices for CFC-12, 5 million cars were retrofitted for HFC-134a use in 1997.<sup>91</sup> This trend toward retrofitting is expected to continue, given that CFC-12 is no longer produced, remaining inventories are being depleted, and CFC-12 prices are expected to rise.<sup>92</sup> Furthermore, many of the air conditioners in mid-1990s vehicle models (which were among the first automobiles to use HFC-134a) are now due to be serviced. In 1999, a spokesperson for Elf Atochem North America estimated the U.S. aftermarket for HFC-134a at 45 to 50 million pounds, or roughly 35 percent of total annual demand. He believed that, as the market for HFC-134a matures, the aftermarket eventually would be about twice the size of the original equipment market.<sup>93</sup> The automotive aftermarket is already responsible for much of the growth in current HFC-134a demand.<sup>94</sup>

<sup>86</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

<sup>87</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

<sup>88</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

<sup>89</sup>Form EIA-1605 is a greenhouse gas emissions and emissions reductions reporting form, which is submitted to EIA on a voluntary basis by entities interested in creating a public record of their emissions reduction activities.

<sup>90</sup>American Automobile Manufacturers Association, *Motor Vehicle Facts and Figures 96* (Detroit, MI, 1999).

<sup>91</sup>"Fluorocarbon Outlook Turns Bullish," *Chemical Market Reporter* (May 25, 1998).

<sup>92</sup>J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

<sup>93</sup>"HFC-134a Prices Rise as Market Tightens," *Chemical Market Reporter* (March 15, 1999).

<sup>94</sup>J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

HFC-134a is also used in refrigerant blends (e.g. R-404A) in most new refrigerators built in the United States and in commercial chillers, but leakage from these sources is much less than from automotive air conditioners. Leakage occurs primarily during servicing of the units rather than during normal operation. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. Such uses include aerosols and open-cell foam blowing, which are denoted as short-term uses because most of the HFC-134a used will be emitted to the atmosphere within a short period of time.

HFCs make attractive solvents because of their non-flammability, thermal and chemical stability, excellent

dielectric properties, high material compatibility, low surface tension and viscosity, and high liquid density. HFC-134a, in particular, is used in special extraction processes to produce important natural active pharmaceuticals, such as taxol for breast cancer treatment, nutraceuticals, flavors, and fragrances.<sup>95</sup>

According to the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), worldwide sales of HFC-134a for short-term applications jumped almost fourfold between 1994 and 1995. Sales for short-term uses leveled off at 10,500 metric tons in 1996 and then dropped to 6,500 metric tons in 1998; however, new developments in the U.S. market have reversed the

### EPA Revises Emissions Estimation Methodology

The primary source for the emission estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, which also prepares an annual inventory of greenhouse gas emissions.<sup>a</sup> The data supporting the EPA inventory for 2002, which includes emissions estimates through 2001, incorporates a number of revisions to the estimates of HFC, PFC, and SF<sub>6</sub> emissions before 2000. Those changes are reflected in the estimates presented in this chapter.

The changes to the historical emission estimates are the result of revisions to the data and estimation methodologies used by the EPA:

- The EPA Voluntary SF<sub>6</sub> Emissions Reduction Partnership to reduce emissions of SF<sub>6</sub> from equipment used to transmit and distribute electricity has new information from its 1999 and 2000 reporters. This, in addition to new information on world sales of SF<sub>6</sub> to electric power systems from 1990 to 1999, has reduced the uncertainty in estimates of SF<sub>6</sub> emissions from electric power systems, resulting in changes from the previously estimated trends in both magnitude and direction. According to the revised estimates, those emissions were nearly unchanged from 1990 to 1994 and decreased from 1995 to 2001.
- The Voluntary Aluminum Industrial Partnership Program and EPA's Climate Protection Partnerships Division continually revise the estimation methods for emissions from aluminum production and the models used to calculate emissions. New

information on aluminum production (smelters) and anode effects led to revisions of the estimates for PFC emissions from 1990 to 1999. The revisions show an average 2.8-percent annual decrease in CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> emissions.

- The methodology for estimating emissions from semiconductor manufacturing has been changed to one based on total annual emissions reported by participants in the PFC Emission Reduction Partnership for the Semiconductor Industry program. The revisions resulted in an average 1.5-percent decrease in annual HFC, PFC, and SF<sub>6</sub> emissions from semiconductor manufacturing for 1990 to 1999.
- For ozone-depleting substance (ODS) substitutes, revisions to chemical substitution trends and new information from industry representatives have led to revised assumptions for the EPA's Vintaging Model, particularly in the areas of cleaning solvents, stationary refrigeration, and fire extinguishing equipment. The revisions resulted in an average 10.6-percent decrease in annual emissions of HFCs, PFCs, and SF<sub>6</sub> from their use as ODS substitutes for 1994 to 1999.
- EPA's correction of an error in the conversion of gigagrams (Gg) of HFC-23 to teragrams (Tg) of carbon dioxide equivalent affected the EPA estimates of HFC-23 emissions from HCFC-22 production for 1990 to 1998. The revision resulted in an average decrease of less than 0.1 percent in annual HFC-23 emissions from the production of HCFC-22.

<sup>a</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

<sup>95</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?applications/solvents/main\\_appli/main.htm](http://www.fluorocarbons.org/frame.htm?applications/solvents/main_appli/main.htm).

downward trend, as sales of HFC-134a totaled 14,300 metric tons in 1999.<sup>96</sup>

In January 1999, the major marketers of tire inflators began requiring the use of nonflammable material, creating additional demand for HFC-134a. Pennzoil was the first company to enter this new market, after removing its hydrocarbon-based canisters and reconfiguring them to use HFC-134a.<sup>97</sup>

For many years, the HFC-134a market was characterized by excess capacity and low prices, because the transition away from CFC-12 occurred more slowly than producers had expected.<sup>98</sup> In 1998 and 1999, however, the market tightened considerably, as evidenced by a series of price increases. Driven in part by a demand surge triggered by an unusually hot summer in 1999, prices nearly doubled, rising from a low of \$1.50 per pound to \$2.50 per pound by September 1999. For the rest of 1999 and the first half of 2000, the market stabilized, with only one minor price increase in early 2000.

A number of HFC-134a producers are undertaking modest capacity expansion projects, including Dupont, INEOSFluor (formerly ICI Klea), and Honeywell (formerly AlliedSignal). More significant additions of new capacity are likely to be needed, however, given that capacity is increasing by only 2 to 3 percent per year, while global demand is growing by 10 percent. According to a representative of Elf Atochem, the market will face significant supply shortages unless more investment in new capacity is undertaken over the next several years.<sup>99</sup> The required capacity will presumably be built, but it is possible that the expansion in supply will lag behind the growth in demand. Anticipating and planning for this growth has proven to be a difficult challenge for producers, who must manage as best as possible an unprecedented transition from an established product (CFC-12) which is being phased out under a global treaty, to a new product (HFC-134a). In the long term, consumption and emissions of HFC-134a will continue to rise rapidly, although it is possible that capacity constraints may act as a brake on consumption in the near term.

## Difluoroethane (HFC-152a)

Estimates of HFC-152a emissions are not provided by the EPA because the data are considered confidential and could affect business practices. As a non-ozone-depleting substance with a GWP of 120,<sup>100</sup> HFC-152a is an attractive potential replacement for CFCs. It can be used as an aerosol propellant, a blowing agent, an ingredient in refrigerant blends (e.g., in R-500), and in fluoropolymer manufacturing applications. There are no HFC-152a emissions associated with the latter application, because the HFC-152a is consumed in the manufacturing process. In 1996, 5 million pounds of HFC-152a was consumed in fluoropolymer manufacturing.<sup>101</sup> HFC-152a is also compatible with the components used in aerosol products. Unlike CFCs, however, HFC-152a is flammable.

Only one U.S. company (DuPont) produces HFC-152a, using the trade name Dymel-152a. DuPont probably was producing HFC-152a at nearly full capacity in 1994, corresponding to production of about 8,000 metric tons. In 1995, the company reported having doubled its production capacity from 1992 levels to 15,875 metric tons.<sup>102</sup> The company reported to EIA's Voluntary Reporting of Greenhouse Gases Program that HFC-152a emissions peaked in 1994 at 181.4 metric tons and dropped to 45.4 metric tons in 2001.

## Other HFCs

Other hydrofluorocarbons with considerable radiative forcing potential include HFC-125, HFC-143a, HFC-227ea, HFC-236fa, and HFC-4310mee, with 100-year GWPs of 3,400, 4,300, 3,500, 9,400, and 1,500, respectively.<sup>103</sup> The EPA estimates total emissions of this group of "other HFCs" (including HFC-152a, HFC-227ea, and HFC-4310mee but not HFC-32, HFC-125, HFC-134a, or HFC-236fa) at 3.3 million metric tons carbon equivalent in 2001, representing 10.5 percent of all emissions of HFCs, PFCs, and SF<sub>6</sub> reported.<sup>104</sup> Emissions of these HFCs are small but growing rapidly, as they continue to find applications as substitutes for

<sup>96</sup>Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site [www.afeas.org/prodsales\\_download.html](http://www.afeas.org/prodsales_download.html).

<sup>97</sup>J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

<sup>98</sup>C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

<sup>99</sup>J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

<sup>100</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

<sup>101</sup>C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

<sup>102</sup>"DuPont Set To Expand Markets for Ozone-Safe HFC-152a Product," *Ozone Depletion Online Today* (Alexandria, VA, June 9, 1995).

<sup>103</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

<sup>104</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002. Note that EIA calculates emissions in carbon-equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.



CFCs and HCFCs. Emissions of “other HFCs” have increased by 6.0 percent since 2000.

The EPA estimates emissions of HFC-125 (pentafluoroethane) at 236 metric tons of gas in 1992, increasing to 1,869 metric tons in 2001.<sup>105</sup> The estimate for 2001 is 19.9 percent higher than the estimate for 2000.<sup>106</sup> HFC-125 is used in the blend R-410A, which is designed to replace HCFC-22 as the refrigerant of choice for stationary commercial refrigeration and air conditioning applications, as well as in blends R-404A and R-507A. Some manufacturers have already introduced air conditioners that use R-410A, but as yet the product has captured only a small percentage of the market. As the phaseout of HCFC-22 begins to gain momentum, Honeywell expects a rapid increase in the demand for R-410A.<sup>107</sup> HFC-125 can also be used as a firefighting agent.

The EPA estimates 1993 emissions of for HFC-143a (trifluoroethane) at 12 metric tons of gas, increasing to 1,142 metric tons in 2001. The 2001 estimate is 26.5 percent higher than the estimate for 2000.<sup>108</sup> HFC-143a is a halocarbon used in blends for commercial refrigeration and air conditioning, such as R-404A, R-406A, R-408A, and R-507A. HFC-143a is used as a substitute because it contains neither chlorine nor bromine and will not emit ozone-depleting halogen radicals into the stratosphere. Like other halocarbons, HFC-143a does make a positive contribution to atmospheric warming; however, its GWP is lower than those of the gases it replaces, such as CFC-11.

The EPA estimates 1997 emissions of HFC-236fa (hexafluoropropane) at 15 metric tons of gas, increasing to 370 metric tons in 2001. The estimate for 2001 is 24.8 percent higher than the estimate for 2000.<sup>109</sup> HFC-236fa is also used as a refrigerant, in particular by the U.S. Navy for shipboard applications.<sup>110</sup> In another application, HFC-236fa is used as a firefighting agent.

Other HFCs and HFC blends are also likely to gain market share as a result of the phaseout of CFCs and HCFCs, because no single product is suited for all applications. For example, each potential replacement product has an optimal operating temperature range; hence,

the refrigerant best suited for use in ice cream freezers will differ from the best choice for milk coolers.<sup>111</sup>

In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, other HFCs are expected to gain new markets as foam blowing agents. CFCs have already been phased out of this market, having been replaced by HCFCs (primarily HCFC-141b). Among the potential replacements, HFC-245fa (pentafluoropropane) appears to be the strongest contender.<sup>112</sup> Demand for Honeywell’s insulating foam agent Enovate™ 3000 (HFC-245fa) is so strong that the company is building a new plant in Geismar, Louisiana, to become fully operational in 2002.<sup>113</sup> Honeywell is also developing blends that combine HFC-245fa with other materials to enhance its cost/performance ratio. To date, however, the foam blowing industry has failed to signal a clear preference for HFC-245fa or other alternatives. Instead, it continues to rely primarily on HCFC-141b while waiting to see which of the possible replacement candidates emerges as the preferred alternative.<sup>114</sup> For some applications, non-fluorochemical alternatives (e.g., hydrocarbons) have been identified.<sup>115</sup>

## Perfluorocarbons (PFCs)

### U.S. Emissions of Perfluorocarbons, 1990-2001

Estimated 2001 Emissions (Million Metric Tons Carbon Equivalent)	2.4
Change Compared to 2000 (Million Metric Tons Carbon Equivalent)	-1.4
Change from 2000 (Percent)	-36.1%
Change Compared to 1990 (Million Metric Tons Carbon Equivalent)	-2.9
Change from 1990 (Percent)	-53.9%

The EPA estimates 2001 emissions of PFCs at 2.4 million metric tons carbon equivalent, 53.9 percent lower than

<sup>105</sup>Preliminary data estimates received by EIA from the EPA’s Office of Air and Radiation, September 2002.

<sup>106</sup>Preliminary data estimates received by EIA from the EPA’s Office of Air and Radiation, September 2002.

<sup>107</sup>J. Ouellette, “Fluorocarbon Market Is Poised To Grow,” *Chemical Market Reporter* (June 19, 2000).

<sup>108</sup>Preliminary data estimates received by EIA from the EPA’s Office of Air and Radiation, September 2002.

<sup>109</sup>Preliminary data estimates received by EIA from the EPA’s Office of Air and Radiation, September 2002.

<sup>110</sup>E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.

<sup>111</sup>C. Boswell, “Hydrofluorocarbons Build with Transition Away from CFCs,” *Chemical Market Reporter* (September 13, 1999).

<sup>112</sup>C. Boswell, “Hydrofluorocarbons Build with Transition Away from CFCs,” *Chemical Market Reporter* (September 13, 1999).

<sup>113</sup>Honeywell International Inc., *Focused on Performance: Annual Report 2001*, web site [www.honeywell.com/investor/otherpdfs/hon2001annualfml.pdf](http://www.honeywell.com/investor/otherpdfs/hon2001annualfml.pdf) (Morristown, NJ, March 2002), p. 9.

<sup>114</sup>C. Boswell, “Hydrofluorocarbons Build with Transition Away from CFCs,” *Chemical Market Reporter* (September 13, 1999).

<sup>115</sup>J. Ouellette, “Fluorocarbon Market Is Poised To Grow,” *Chemical Market Reporter* (June 19, 2000).



1990 emissions (Table 30).<sup>116</sup> The decrease is the result of improvements in the aluminum industry, which creates PFCs as byproducts; all increases in PFC emissions are from industrial applications, such as semiconductor manufacturing. PFCs are compounds composed of carbon and fluorine. PFC emissions are not regulated, although their high GWPs (5,700 for perfluoromethane [CF<sub>4</sub>] and 11,900 for perfluoroethane [C<sub>2</sub>F<sub>6</sub>])<sup>117</sup> have drawn attention. PFCs are also characterized by long atmospheric lifetimes (up to 50,000 years); hence, unlike HFCs, they are essentially permanent additions to the atmosphere. PFCs are used in semiconductor manufacturing and as heat transfer fluids (dielectric liquids) for indirect contact cooling of electronics.<sup>118</sup>

The principal quantifiable source of PFCs is as a byproduct of aluminum smelting created during periods of process inefficiency and disruption. The amount created depends on the frequency and duration of the events. The EPA estimates U.S. emissions from aluminum production at 551 metric tons of perfluoromethane and 60 metric tons of perfluoroethane in 2001.<sup>119</sup> Reductions in primary aluminum production and efficiency improvements to reduce anode effects leading to process inefficiency have reduced emissions of perfluoromethane and perfluoroethane from this source by 77.4 percent and 75.9 percent, respectively, since 1990.

Aluminum smelting companies that participate in EPA's Voluntary Aluminum Industry Partnership (VAIP) program have achieved many efficiency improvements through voluntary actions. Reductions in primary aluminum production have also played a role in reducing PFC emissions. According to data from the U.S. Geological Survey, domestic primary aluminum production decreased significantly in 2001 as a result of cutbacks in smelter production, which in turn were caused by increased energy costs and reduced energy supply in the Pacific Northwest.<sup>120</sup>

Another source of PFC emissions is semiconductor manufacturing. For 2001, the EPA estimates emissions of perfluoromethane and perfluoroethane from

semiconductor manufacturing at 217 metric tons and 326 metric tons of gas, respectively.<sup>121</sup> Both estimates reflect the rapid growth of the semiconductor industry in the 1990s, which resulted in increases of 95.5 percent and 94.9 percent in emissions of perfluoromethane and perfluoroethane, respectively, since 1990. Perfluoromethane and perfluoroethane are used as plasma etchants and cleaning agents in semiconductor manufacturing; some of the gas used in those processes does not react with the materials and, unless captured, is emitted to the atmosphere. A variety of other perfluorinated compounds are used in the semiconductor industry, including perfluoropropane (C<sub>3</sub>F<sub>8</sub>, with a GWP of 8,600), perfluorobutane (C<sub>4</sub>F<sub>10</sub>, GWP 8,600), perfluorohexane (C<sub>6</sub>F<sub>14</sub>, GWP 9,000), and nitrogen trifluoride (NF<sub>3</sub>, manufactured by Air Products).<sup>122</sup>

It is difficult to assess trends in PFC emissions from the semiconductor industry. On the one hand, the continued expansion of the worldwide semiconductor market may lead to increased PFC use and emissions. On the other hand, voluntary industry efforts to curb emissions are helping to offset production increases to some extent. The semiconductor industry has introduced new methods to slow or even reverse the increase in PFC emissions.

The global semiconductor industry has also committed to further reductions in PFC emissions. In 1999, the World Semiconductor Council, consisting of manufacturers from Europe, the United States, Japan, and Korea, voluntarily committed to reduce emissions of PFCs by 10 percent from 1995 levels by 2010.<sup>123</sup> A number of semiconductor manufacturing firms also participate in the EPA's PFC Emission Reduction Partnership for the Semiconductor Industry with the goal of voluntarily reducing PFC emissions and reporting to the EPA.<sup>124</sup>

## Sulfur Hexafluoride (SF<sub>6</sub>)

The most recent EPA estimates show a steady decrease in U.S. emissions of sulfur hexafluoride (SF<sub>6</sub>), from a

<sup>116</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002. Note that EIA calculates emissions in carbon-equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

<sup>117</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

<sup>118</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?chfamilies/PFCs/prod\\_main/prod.htm](http://www.fluorocarbons.org/frame.htm?chfamilies/PFCs/prod_main/prod.htm).

<sup>119</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

<sup>120</sup>U.S. Geological Survey, Mineral Commodity Summaries (January 2001), web site <http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/050301.pdf>.

<sup>121</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

<sup>122</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

<sup>123</sup>World Semiconductor Council, "Position Paper Regarding PFC Emissions Reduction Goal," April 26, 1999, web site [www.semiconductorcouncil.org/news/pfc.html](http://www.semiconductorcouncil.org/news/pfc.html).

<sup>124</sup>U.S. Environmental Protection Agency, "Voluntary Aluminum Industrial Partnership," web site [www.epa.gov/highgwp1/vaip/](http://www.epa.gov/highgwp1/vaip/).

**U.S. Emissions of Sulfur Hexafluoride, 1990-2001**

Estimated 2001 Emissions (Million Metric Tons Carbon Equivalent)	4.7
Change Compared to 2000 (Million Metric Tons Carbon Equivalent)	-0.3
Change from 2000 (Percent)	-6.7%
Change Compared to 1990 (Million Metric Tons Carbon Equivalent)	-4.9
Change from 1990 (Percent)	-50.8%

peak of 1,772 metric tons of gas in 1993 to 780 metric tons in 2001, representing an overall decrease of 50.8 percent since 1990.<sup>125</sup> The decrease is the result of industry efforts to reduce emissions from electrical power systems, the rising cost of SF<sub>6</sub>, and the closure of a major U.S. magnesium production facility. Emissions of SF<sub>6</sub> from uses in the semiconductor manufacturing industry have increased. Although it is not emitted in large quantities, SF<sub>6</sub> has a very high GWP of 22,200.<sup>126</sup>

SF<sub>6</sub> is used primarily in electrical applications and metal casting processes. SF<sub>6</sub> is an excellent dielectric gas for high-voltage applications, because it is chemically inert, gaseous at low temperatures, nonflammable, nontoxic, and noncorrosive.<sup>127</sup> In electrical transmission and distribution systems, SF<sub>6</sub> acts as an insulator for circuit breakers, switch gear, and other electrical equipment; however, it can escape through seals, especially in older equipment. Emissions also occur during equipment installation, servicing, and disposal.<sup>128</sup> Between 70 and

80 percent of global SF<sub>6</sub> production is used in electricity transmission and distribution.<sup>129</sup>

Other applications that produce SF<sub>6</sub> emissions include magnesium and aluminum metal casting processes that employ SF<sub>6</sub> to replace toxic and corrosive materials, such as salt fluxes and sulfur dioxide (SO<sub>2</sub>). Another important use of SF<sub>6</sub> is as a cover gas during magnesium production and processing to prevent excessive oxidation of molten magnesium in the presence of air. Pre-treating aluminum melt with SF<sub>6</sub> (or an inert gas mixture) prevents porosity and therefore weakening of the metal. It also removes oxides and solid impurities. In addition, mixtures of SF<sub>6</sub> and O<sub>2</sub> are used as feed gases for plasma etching of semiconductor devices.<sup>130</sup> Because of its extremely low atmospheric concentration, SF<sub>6</sub> is also useful as an atmospheric tracer gas for a variety of experimental purposes. Other minor applications include leak detection, loud speakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.<sup>131</sup>

In compiling its estimates, the EPA receives data from participants in the SF<sub>6</sub> Emissions Reduction Partnership for Electric Power Systems and the SF<sub>6</sub> Emissions Reduction Partnership for the Magnesium Industry. The uncertainty associated with SF<sub>6</sub> emissions in the electric power industry is noteworthy, because the data reported cover only 1999, 2000, and 2001, and a model was necessary to “backcast” emissions for 1990 to 1998, as well as for those utilities not reporting to the program. A major model assumption made regarding magnesium processing, that SF<sub>6</sub> neither reacts nor decomposes, adds an element of uncertainty to the estimates.<sup>132</sup>

<sup>125</sup>Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2002.

<sup>126</sup>Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

<sup>127</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?chfamilies/SF6/prod\\_main/prod.htm](http://www.fluorocarbons.org/frame.htm?chfamilies/SF6/prod_main/prod.htm).

<sup>128</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

<sup>129</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?applications/electri\\_appli/main\\_appli/main.htm](http://www.fluorocarbons.org/frame.htm?applications/electri_appli/main_appli/main.htm).

<sup>130</sup>European Fluorocarbon Technical Committee, web site [www.fluorocarbons.org/frame.htm?applications/electri\\_appli/main\\_appli/main.htm](http://www.fluorocarbons.org/frame.htm?applications/electri_appli/main_appli/main.htm).

<sup>131</sup>Historically, emissions of SF<sub>6</sub> from the aluminum industry have been omitted from global estimates, because any emissions are expected to be insignificant. The EPA does not estimate emissions from this source due to uncertainties about the quantities used and the amounts destroyed in the applications.

<sup>132</sup>U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2000*, EPA-430-R-02-003 (Washington, DC, April 2002), web site [www.epa.gov](http://www.epa.gov).

**Table 29. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2001**  
(Thousand Metric Tons of Gas)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
<b>Hydrofluorocarbons</b>												
HFC-23	3.0	2.6	3.0	2.7	2.7	2.3	2.7	2.6	3.5	2.7	2.6	1.8
HFC-125	*	*	0.2	0.5	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.9
HFC-134a	0.6	0.6	0.6	2.9	4.5	12.2	16.2	20.2	23.1	26.1	28.9	31.6
HFC-143a	*	*	*	*	0.1	0.1	0.2	0.3	0.5	0.7	0.9	1.1
HFC-236fa	*	*	*	*	*	*	*	*	0.1	0.2	0.3	0.4
Other HFCs												
HFC-152a	W	W	W	W	W	W	W	W	W	W	W	W
HFC-227ea	W	W	W	W	W	W	W	W	W	W	W	W
HFC-4310mee	W	W	W	W	W	W	W	W	W	W	W	W
<b>Perfluorocarbons</b>												
CF <sub>4</sub>	2.5	2.2	2.1	2.0	1.8	1.8	1.9	1.8	1.5	1.5	1.4	0.8
C <sub>2</sub> F <sub>6</sub>	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.5	0.4
C <sub>4</sub> F <sub>10</sub>	*	*	*	*	*	*	*	*	*	*	*	*
PFCs/PFPEs	W	W	W	W	W	W	W	W	W	W	W	W
<b>Sulfur Hexafluoride</b>	<b>1.6</b>	<b>1.6</b>	<b>1.5</b>	<b>1.7</b>	<b>1.6</b>	<b>1.4</b>	<b>1.5</b>	<b>1.4</b>	<b>1.2</b>	<b>1.0</b>	<b>0.8</b>	<b>0.8</b>

\*Less than 50 metric tons of gas.

P = preliminary data. W = withheld to avoid disclosure of confidential data.

Note: Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (preliminary estimates, September 2002).

**Table 30. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2001**  
(Million Metric Tons Carbon Equivalent)

Gas	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	P2001
<b>Hydrofluorocarbons</b>												
HFC-23	9.8	8.6	9.8	8.9	8.9	7.6	8.8	8.5	11.4	8.7	8.5	5.8
HFC-125	*	*	0.2	0.4	0.3	0.4	0.6	0.8	1.0	1.2	1.4	1.7
HFC-134a	0.2	0.2	0.2	1.0	1.6	4.3	5.7	7.1	8.2	9.3	10.2	11.2
HFC-143a	*	*	*	*	0.1	0.1	0.2	0.4	0.6	0.8	1.1	1.3
HFC-236fa	*	*	*	*	*	*	*	*	0.3	0.5	0.8	0.9
<b>Total</b>	<b>10.0</b>	<b>8.8</b>	<b>10.2</b>	<b>10.4</b>	<b>10.8</b>	<b>12.6</b>	<b>15.4</b>	<b>16.9</b>	<b>21.5</b>	<b>20.5</b>	<b>22.1</b>	<b>21.0</b>
<b>Perfluorocarbons</b>												
CF <sub>4</sub>	4.0	3.5	3.2	3.1	2.8	2.9	3.0	2.7	2.4	2.4	2.1	1.2
C <sub>2</sub> F <sub>6</sub>	1.4	1.2	1.2	1.2	1.2	1.6	1.5	1.7	1.7	1.8	1.7	1.3
C <sub>4</sub> F <sub>10</sub>	*	*	*	*	*	*	*	*	*	*	*	*
<b>Total</b>	<b>5.3</b>	<b>4.7</b>	<b>4.4</b>	<b>4.4</b>	<b>4.1</b>	<b>4.5</b>	<b>4.5</b>	<b>4.4</b>	<b>4.1</b>	<b>4.2</b>	<b>3.8</b>	<b>2.4</b>
<b>Other HFCs, PFCs/PFPEs</b>	<b>*</b>	<b>*</b>	<b>*</b>	<b>*</b>	<b>0.4</b>	<b>1.2</b>	<b>1.0</b>	<b>2.4</b>	<b>2.7</b>	<b>2.9</b>	<b>3.1</b>	<b>3.3</b>
<b>Sulfur Hexafluoride</b>	<b>9.6</b>	<b>9.9</b>	<b>9.4</b>	<b>10.4</b>	<b>9.7</b>	<b>8.6</b>	<b>8.9</b>	<b>8.2</b>	<b>7.0</b>	<b>6.0</b>	<b>5.1</b>	<b>4.7</b>
<b>Total Emissions</b>	<b>25.0</b>	<b>23.4</b>	<b>24.0</b>	<b>25.3</b>	<b>25.0</b>	<b>26.8</b>	<b>30.9</b>	<b>32.0</b>	<b>35.3</b>	<b>33.6</b>	<b>34.1</b>	<b>31.4</b>

\*Less than 50,000 metric tons carbon equivalent.

P = preliminary data.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site [www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) (preliminary estimates, September 2002).

